

40-Gb/s Dense Wavelength Division Multiplexing Transmission System

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Fujitsu Telecom Networks develops and supplies optical transmission systems for domestic telecommunications carriers. For Japanese telecommunications carriers, it has recently developed the world's first 40-Gb/s dense wavelength division multiplexing (DWDM) transmission system using the return-to-zero differential quaternary phase shift keying (RZ-DQPSK) modulation format. This system can multiplex and transmit up to forty 40-Gb/s (STM-256) signals (total: 1.6 Tb/s) over one optical fiber. In this paper, we explain the technical problems and solutions for multiplexing 40-Gb/s optical signals on a DWDM system, discuss the characteristics of various optical modulation formats, and show the superiority of RZ-DQPSK.

1. Introduction

Dense wavelength division multiplexing (DWDM) is a transmission system that enables more efficient utilization of optical fiber by multiplexing and simultaneously transmitting multiple optical signals of different wavelengths. Up to now, the maximum transmission speed in services provided by telecommunications carriers in Japan has been 10 Gb/s, but as routers and other devices undergo performance upgrades, they are getting 40-Gb/s interfaces, which creates the need for a DWDM system that can transmit at 40 Gb/s over long distances.

The distance that signals can be transmitted over optical fiber decreases as the signal transmission speed increases. This is because distortion of the signal waveform caused by the nonlinear properties of the optical fiber can degrade the optical signal-to-noise ratio (OSNR), wavelength dispersion resistance, and polarization mode dispersion (PMD) resistance, thereby preventing long-distance transmission from being achieved. Although this nonlinearity can be ignored in 10-Gb/s transmission, it cannot

be ignored in 40-Gb/s transmission.

Since a station arrangement and maintenance system have already been set up for a 10-Gb/s DWDM system by telecommunications carriers, it is especially attractive to have a 40-Gb/s DWDM system with the same station arrangement and transmission performance. With this in mind, Fujitsu Telecom Networks has used new technology to solve the problems created by the difference between 10- and 40-Gb/s transmission speeds and has developed a 40-Gb/s DWDM system that achieves the same transmission distance as the existing 10-Gb/s DWDM system.

2. System overview

This system accommodates digital signals with a transmission rate of 40 Gb/s (STM-256^{note 1)})

note 1) STM: Synchronous transfer mode. The STM-1 frame corresponds to a bitrate of 155.520 Mb/s. STM-256 corresponds to a line rate of almost 40 Gb/s (39.813120 Gb/s). STM-64 corresponds to a line rate of almost 10 Gb/s (9.953280 Gb/s).

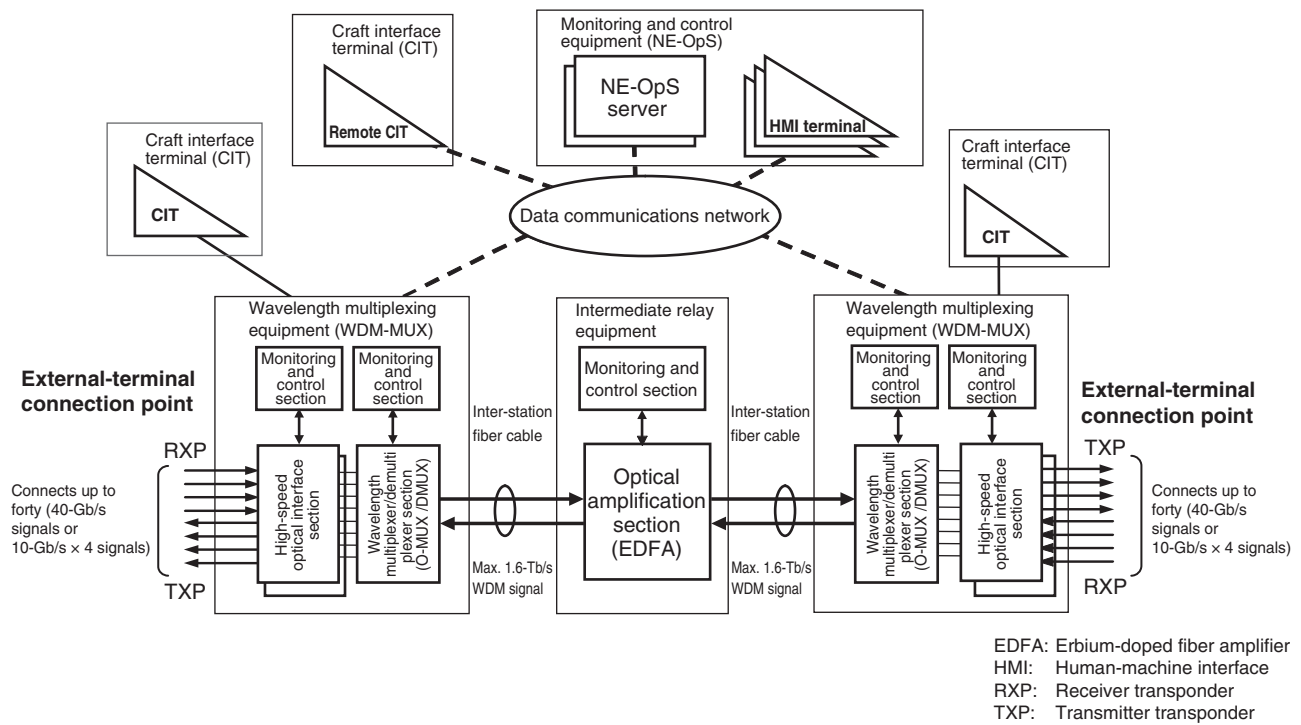


Figure 1
40-Gb/s DWDM system configuration.

or 10 Gb/s (STM-64, 10GbE^{note 2)} (when 10-Gb/s signals are carried, four signals are multiplexed into a 43-Gb/s OTU3^{note 3)} signal), multiplexes/demultiplexes up to 40 wavelengths of 43-Gb/s OTU3 signals, and performs long-distance transmission via optical amplification relays. The DWDM system consists of four components, as shown in **Figure 1**.

1) Wavelength multiplexing equipment (WDM-MUX)

This consists of two sections, each having an independent monitoring and control section: 1) a high-speed optical interface (transmitter/receiver transponder) section^{note 4)} (transponder section)

note 2) 10GbE: 10 Gigabit Ethernet (10 Gb/s).
 note 3) OTU3: Optical channel transport unit 3. A line rate defined by ITU-T for the Optical Transport Network in Standard G.709. OTU3 was designed to transport STM-256 signals and has a line rate of approximately 43 Gb/s.
 note 4) This section functions as a transmitter and receiver when one thinks partially of the network and as a transponder when one thinks of the network's input/output point.

and 2) a wavelength multiplexer/demultiplexer (O-MUX/DMUX) section (core section). The transponder section takes a wideband optical signal from client equipment and converts it to narrowband optical signals suitable for wavelength multiplexing. In the case of 10-Gb/s signals, the transponder section performs bit multiplexing/demultiplexing of four signal lines to and from a 43-Gb/s OTU3 signal. This is followed by return-to-zero differential quadrature phase shift keying (RZ-DQPSK) modulation/demodulation, individual dispersion compensation, and forward error correction (FEC).

The core section takes 43-Gb/s OTU3 signals from the transponder section and multiplexes them into 40 signals of different wavelengths. The monitoring and control sections connect to monitoring and control equipment via a local area network to control the transponder and core sections and collect state information.

2) Intermediate relay equipment

This consists two sections for amplifying and relaying a WDM optical signal formed by the 40-wavelength multiplexing of 43-Gb/s OTU3 signals. The optical amplification section has an erbium-doped optical fiber amplifier and a Raman amplifier to intensify and relay the optical signal in optical form. The monitoring and control section connects to monitoring and control equipment via the local area network to control the optical amplification section and to collect state information.

3) Monitoring and control equipment (NE-OpS)

This consists of a network element operations system (NE-OpS) server and human-machine-interface user terminals. It monitors and controls the operation of multiple units of wavelength multiplexing equipment and intermediate relay equipment.

4) Craft interface terminal

The craft interface terminal (CIT) is a local terminal that connects directly to equipment installed at an exchange. It can be used to control settings in wavelength multiplexing equipment and intermediate relay equipment when lines are set up and to control and monitor the operation of that equipment. Some of these functions can be performed remotely over the network using a remote CIT.

3. Technical issues in 40-Gb/s transmission

To achieve a transmission distance equivalent to that of 10-Gb/s systems for 40-Gb/s signals, we must overcome the degradation of OSNR, wavelength dispersion resistance, and PMD resistance. These issues are outlined below.

1) Degradation of OSNR

Given the same modulation/demodulation system, a 40-Gb/s system whose signal bandwidth is four times that of a 10-Gb/s system will have four times the intra-band noise, resulting in an OSNR on the transmission channel 6 dB lower

than the 10-Gb/s system.

2) Degradation of wavelength dispersion resistance

When light waves of different wavelengths pass through an optical fiber, each will experience a different index of refraction resulting in slight differences in propagation speed. This property, which is called wavelength dispersion, means that signals launched at the same time will arrive at a range of times and the overall signal waveform will be degraded as a result. The resistance to wavelength dispersion decreases in inverse proportion to the square of the signal speed, which means that the value for a 40-Gb/s system will be 1/16 compared with 10-Gb/s system.

3) Degradation of PMD resistance

An optical pulse is transmitted along an optical fiber as a synthesis of two orthogonally polarized waves, but a difference in the group velocities of these two polarized waves causes the pulse to spread (disperse). The resistance to PMD decreases in inverse proportion to the signal speed, which means that the value for a 40-Gb/s system will be 1/4 compared with 10-Gb/s system.

4. New application technologies

The degradation can be overcome by using some newly developed technologies. These technologies and their application to our system are discussed below.

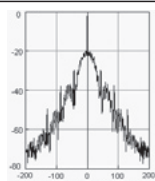
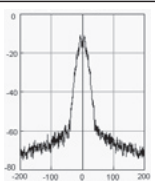
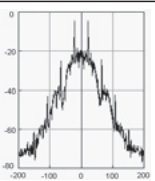
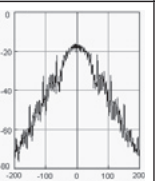
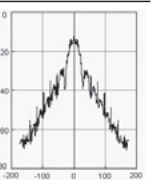
4.1 Differential quadrature phase shift keying

Our system is the first in the world to apply RZ-DQPSK as a modulation/demodulation format. As shown in **Table 1**, the RZ-DQPSK format is superior to other 40-Gb/s modulation/demodulation formats in terms of the following characteristics, so it is advantageous in achieving long-distance transmission.

1) Optical noise resistance

Compared with the other modulation/demodulation formats, RZ-DQPSK features good

Table 1
Comparison of 40-Gb/s optical modulation formats.

Modulation format	NRZ	Duobinary	CS-RZ	RZ-DPSK	RZ-DQPSK
Optical spectral shape					
1) Optical noise resistance	×	×	△	○	○
2) Wavelength dispersion resistance	△	○	×	×	○
3) Nonlinearity resistance	△	×	○	○	○
4) PMD resistance	×	△	△	△	○
5) Optical filter transparency	○	◎	△	×	◎

◎ : very good ○ : good △ : normal × : poor

optical noise resistance as a result of differential reception using an optical delay interferometer and TWIN-PIN photodiode^{note 5)} and RZ pulses. Although the duobinary format has strong wavelength dispersion resistance, its optical noise resistance is significantly worse (about 6 dB) than that of RZ-DQPSK because of the effects of inter-symbol interference that generally occurs. Consequently, the duobinary format is not applicable to long-distance transmission.

2) Wavelength dispersion resistance

The RZ-DQPSK format features a symbol rate of 20 gigabaud, which provides an optical spectrum width about 60% of that of the non-return-to-zero (NRZ) format and a time slot that is twice as large. The wavelength dispersion resistance of RZ-DQPSK is about three times as broad as that of NRZ.

3) Nonlinearity resistance

The RZ-DQPSK format has a clock-pulse-type (RZ-like) optical power waveform, which gives it a fiber nonlinearity resistance about the

same as the carrier-suppressed return-to-zero (CS-RZ) format and higher than NRZ.

4) PMD resistance

In RZ-DQPSK, one time slot is twice as large as in the other modulation/demodulation formats, so the PMD resistance is about twice as high, which corresponds to a transmission distance that is about four times as long.

5) Optical filter transparency

With a symbol rate of 20 gigabaud, the RZ-DQPSK format has a narrow optical spectrum width, which provides superb optical filter transparency. RZ-DQPSK is therefore applicable to transmission-capacity expansion by DWDM and to optical add/drop multiplexer systems for multistage switching devices.

4.2 High-gain forward error correction

FEC is a well-known technology for correcting data errors on the transmission path by adding redundant information to the information that the user wishes to send. Our system uses high-gain FEC—an enhancement of the existing Reed-Solomon (255, 239) FEC code—to improve reception strength.

note 5) Photodiode with a dual junction structure having a nearly intrinsic region between the positive- and negative-type semiconductor regions.

4.3 Individual dispersion compensation technology

Dispersion compensation fiber is used to compensate for dispersion in the optical fiber with the aim of achieving 100% compensation for transmission-path dispersion in each span at each node. However, residual dispersion in each channel cannot be completely compensated for because of the dispersion slope and dispersion variation. In addition to improving wavelength dispersion resistance by using the RZ-DQPSK format, our system uses an individual dispersion compensator to compensate for dispersion in each channel; in this way, it compensates for the residual dispersion that could not be compensated for by the dispersion compensation fiber. Moreover, to keep up with wavelength dispersion fluctuation on the transmission path caused by fluctuations in air temperature and other factors, the individual dispersion compensator has a variable adjustment system and performs dispersion control to ensure that an optimal dispersion value is automatically achieved at all times.

5. Application to equipment

Our system was designed to extend the transmission speed up to 40 Gb/s by building upon the 10-Gb/s DWDM system already proven in the field. We set the optical levels at the ports of the transponder and core sections to the same values as in the 10-Gb/s system. This choice of architecture let us reuse the core section of the existing 10-Gb/s system and minimized the changes needed in the optical-circuit design rules, which eliminated significant design costs. Furthermore, after implementing all of the new technologies together on the transponder unit, we were able to achieve the same operability and maintainability as the 10-Gb/s system in a volume less than twice that of the 10-Gb/s transponder. The functional configuration of the 40-Gb/s transponder incorporating these new technologies is shown in **Figure 2** and a photograph of it is shown in **Figure 3**. This transponder accommodates 40-Gb/s (STM-256) optical signals from the client side and performs wavelength conversion, RZ-DQPSK modulation/demodulation, FEC, and individual dispersion compensation.

In more detail, the 40-Gb/s transponder

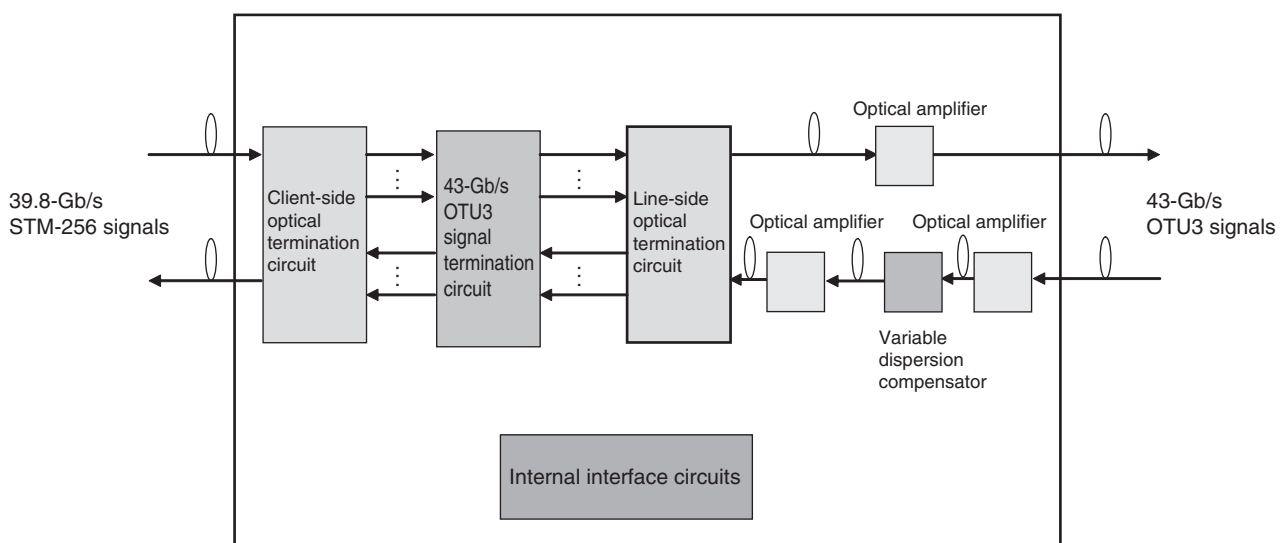


Figure 2
Functions of 40-Gb/s transponder.

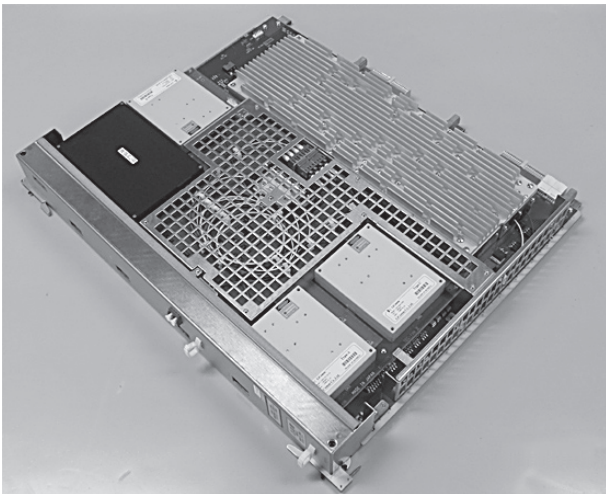


Figure 3
40-Gb/s transponder unit.

performs optical-to-electrical (O-E) conversion on 39.8-Gb/s (STM-256) optical signals, adds the OTU3 overhead, and performs FEC, electrical-to-optical (E-O) conversion, and wavelength conversion. Then, after performing RZ-DQPSK modulation, it forwards the signals to the core section. The transponder also receives 43-Gb/s OTU3 optical signals from the core section and performs individual dispersion compensation, O-E conversion, and FEC on those signals. It

then extracts the original STM-256 signals from the OTU3 frame, performs E-O conversion again, and sends the signals to the client equipment.

6. Conclusion

Application technologies that can handle even higher transmission speeds are needed for transmission equipment in consideration of future increases in traffic. The 40-Gb/s DWDM system introduced here meets those expectations. Fujitsu is promoting the application of the 40-Gb/s long-distance transmission technologies established for this 40-Gb/s DWDM system to 40-Gb/s ring and mesh systems to handle future traffic levels.

In the future, high-speed optical transmission for 100-Gb/s next-generation systems will no doubt be an enormous challenge, but the Fujitsu Group intends to use its technical expertise to find solutions to the problems and create systems that meet customers' needs. Fujitsu researchers will also work to reduce the power consumption of elemental technologies and to downsize system equipment with the aim of reducing CO₂ emissions and improving floor installation density.



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